MISCELLANEOUS PAPER N-68-5

RESPONSE OF DEEP REINFORCED AND UNREINFORCED CONCRETE SLABS TO STATIC AND DYNAMIC LOADING

by

G. E Albritton

October 1968

Sponsored by

Defense Atomic Support Agency

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

38

MISCELLANEOUS PAPER N-68-5

RESPONSE OF DEEP REINFORCED AND UNREINFORCED CONCRETE SLABS TO STATIC AND DYNAMIC LOADING

by

G. E Albritton

October 1968

Sponsored by

Defense Atomic Support Agency

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

The paper was prepared for presentation at the American Society of Civil Engineers Structural Engineering Conference to be held in Pittsburgh, Pennsylvania, in September 1968.

The research reported herein was conducted at the U. S. Army Engineer Waterways Experiment Station under the sponsorship of the Defense Atomic Support Agency. The work was accomplished under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief of the Nuclear Weapons Effects Division, and under the direct supervision of Mr. W. J. Flathau, Chief of the Protective Structures Branch. This paper was prepared by Mr. G. E. Albritton of the Projects Group. Acknowledgment is made to 1LT K. M. Cole who assisted in all phases of the study at WES.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the Waterways Experiment Station during this study. Mr. J. B. Tiffany was Technical Director.

SUMMARY

The objectives of this investigation were to study experimentally the response of deep, two-way reinforced and plain concrete slabs subjected to static overpressures and to determine the response to failure of deep slabs subjected to airblast overpressure. In the static program, tests were conducted on twenty-one deep-slab specimens having a constant span-to-thickness ratio of 4.12. The parameters varied during the tests were the steel percentage and concrete strength; also the study included tests on plain concrete slabs. Six additional deep slabs were included in a field test, with three slabs having a span-to-thickness ratio of 3.5 and three a ratio of 2.6. All of the slabs had a model scale ratio of 1/7 of the assumed prototype deep slab, had a constant square length of 30.25 inches, and were supported flat over a 24-inch-diameter clear span. The magnitude of static failure overpressures ranged from 695 psi for the low strength plain concrete slabs to 1,432 psi for the slabs containing reinforcement and having a high concrete strength of 4,590 psi. The slabs tested in the field were subjected to an apparent airblast overpressure of approximately 5,000 to 6,000 psi. Collapse of the slabs was instantaneous and very catastrophic, and the mode of failure for all slabs was shear. The results from the static tests indicated that the slabs had low ductility ratios of approximately 2 to 3. The tests have shown that increase in tensile reinforcement from 0.99 to 1.49 percent does not appreciably change the resistance of the slab. The failure overpressures for plain concrete deep slabs were less, although not significantly, than those for reinforced concrete slabs with comparable concrete strengths. In the field test, the airblast overpressure was greater than that required to fail the slabs; however, there was no evidence to indicate that the dynamic load capacities were lower than the static load capacities.

BLANK PAGE

RESPONSE OF DEEP REINFORCED AND UNREINFORCED

CONCRETE SLABS TO STATIC AND

DYNAMIC LOADING

By Gayle E. Albritton,[1] A.M. ASCE

INTRODUCTION

APPROACH

The entrance systems for hardened facilities, i.e. missile silos, command or control centers, etc., must be designed to resist high overpressures. It is reasonable to expect that such facilities may be located in regions subjected to overpressures greater than 1,000 psi. For this reason, deep, reinforced concrete slabs, which have a much greater load-carrying capacity than conventional shallow slabs, are considered feasible for such systems. Currently, only limited experimental information is available concerning the response of such deep structures. Therefore, there is a need to examine target-analysis procedures and to determine experimentally the response of deep slabs to high-intensity transient loads. The study reported herein is a summary of the work to date on a continuing effort to accomplish this task.

OBJECTIVES

The general objective of this investigation was to determine the response of deep, reinforced concrete slabs subjected to airblast from nuclear detonations, and to evaluate procedures for analyzing the target

---

[1]Project Manager, Projects Group, Protective Structures Branch, Nuclear Weapons Effects Division, U. S. Army Engineer Waterways Experiment Station.

vulnerability of structures of this nature. Specifically, the objectives were to study experimentally the response of deep, two-way reinforced and plain concrete slabs subjected to static overpressures and to determine the response to failure of deep slabs subjected to airblast overpressure in the field.

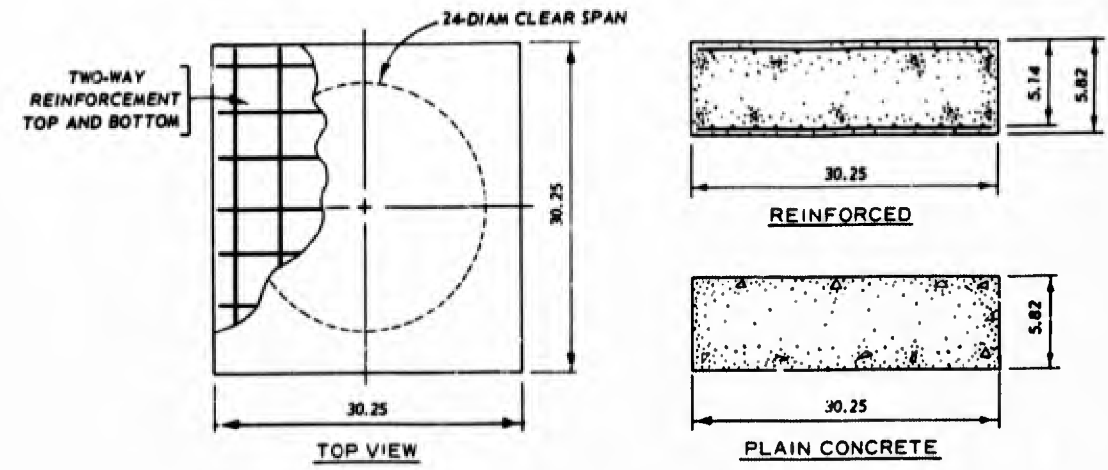
SCOPE

In this study, static tests were conducted on twenty-one deep-slab specimens having a constant span-to-thickness ratio, L/t, of 4.12. Six additional deep-slab specimens were included in a field test, with three slabs having an L/t ratio of 3.5 and three a ratio of 2.6. All of the slabs had a model scale ratio of 1/7 of the assumed prototype deep slab, had a constant square length of 30.25 inches, and were supported on flat steel plates over a 24-inch-diameter clear span. The parameters varied during the tests were the steel percentage and concrete strength; also, the study included tests on plain concrete slabs.

EXPERIMENTAL PROCEDURES

DESCRIPTION OF STATIC TEST SLABS

The static test program was conducted in three tasks with the slabs in each task having one major variable parameter. All slabs had similar geometries with a constant L/t ratio of 4.12 (Fig. 1). For Task A, the nine slabs had two-way tensile and compressive reinforcement percentages of 0.99 and 0.50, respectively (Fig. 1); however, the concrete compressive strength was varied for each of the three series of slabs as given in Table 1. For Task B, the parameter varied was the reinforcement: three slabs had increased tensile reinforcement of 1.49 percent, and three slabs



PHASE 1 TEST PARAMETERS

	NO. OF SPECIMENS	L/t	L/d	f'_c psi	p pct	p' pct
TASK A	3	4.12	4.67	2390	0.99	0.50
	3	4.12	4.67	3370	0.99	0.50
	3	4.12	4.67	4590	0.99	0.50
TASK B	3	4.12	4.67	3600	1.49	0.50
	3	4.12	—	3320	0	0
TASK C	3	4.12	—	2730	0	0
	3	4.12	—	5250	0	0

Fig. 1. Geometries and parameters of deep-slab static test specimens; dimensions in inches

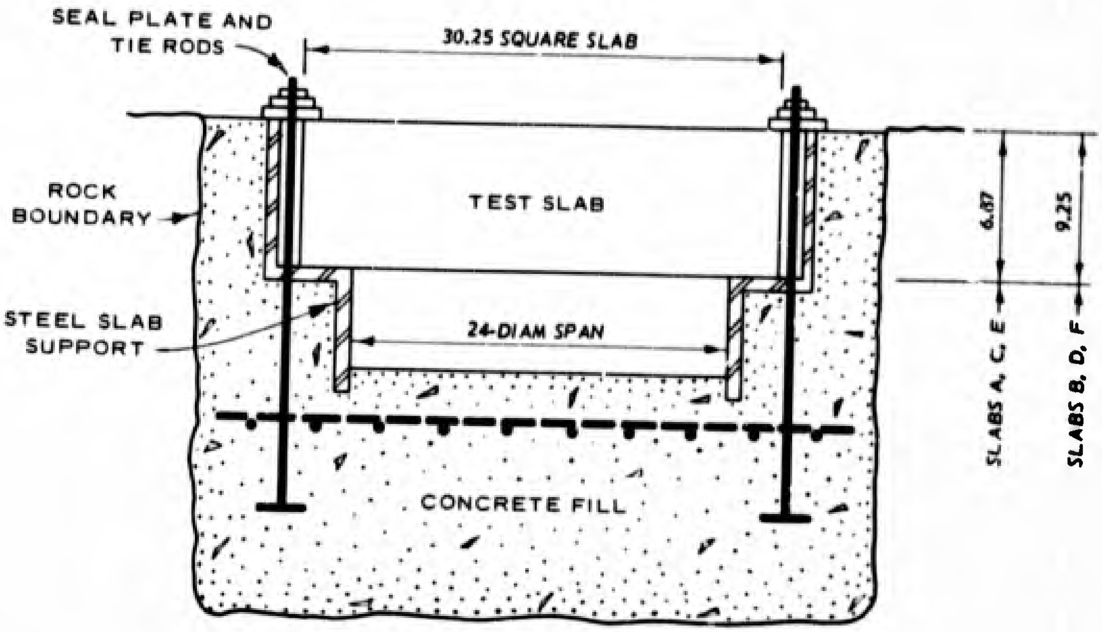
were constructed of plain concrete (Fig. 1). The six slabs in Task C were constructed of plain concrete with three slabs having a concrete strength of approximately 2,730 psi and three a strength of 5,250 psi.

In order to ensure that anchorage failure would not occur during the tests, the tensile reinforcing bars were welded together at intersection points along the outside periphery of the reinforcing mat. The reinforcement used in all the slabs was commercially available, No. 3, deformed, intermediate-grade steel bars having a yield strength of approximately 50,000 psi. The concrete mix for all specimens consisted of 3/8-inch maximum size limestone aggregates.

DESCRIPTION OF FIELD TEST SLABS

Six deep-slab specimens were included in the field test with three slabs each having L/t ratios of 3.5 and 2.6 (Fig. 2). Slabs that are deeper than those previously tested in the laboratory were used due to the high overpressure of the test. Additionally, the two L/t ratios were used in order to bracket the failure overpressure.

The three slabs with an L/t ratio of 3.5 were designed to have the same concrete strength of approximately 5,000 psi; however, two slabs had tensile and compressive reinforcement of 1.00 and 0.47 percent, respectively, and one slab consisted of plain concrete (Fig. 2 and Table 2). The three slabs having an L/t ratio of 2.6 were designed in the same manner except that the concrete strength was 3,150 psi and two slabs contained tensile and compressive reinforcement of 1.02 and 0.51 percent, respectively. It was anticipated that the shallower slabs with increased concrete strength and the deeper slabs with lower concrete strength would aid in bracketing the failure overpressure. One slab each of the two sets (Slabs A and B) was



TYPICAL SECTION

FIELD TEST PARAMETERS

SLAB NO.	L/t	L/d	f'_c psi	p pct	p' pct
A	3.5	3.88	5550	1.00	0.47
C	3.5	3.88	5550	1.00	0.47
E	3.5	---	4750	0	0
B	2.6	2.8	3150	1.02	0.51
D	2.6	2.8	3150	1.02	0.51
F	2.6	---	3150	0	0

Fig. 2. Geometry and parameters of deep-slab field test specimens; dimensions in inches

constructed with internal bearing steel over the supports.

The type reinforcing steel and concrete mix were the same as previously described for the static laboratory specimens.

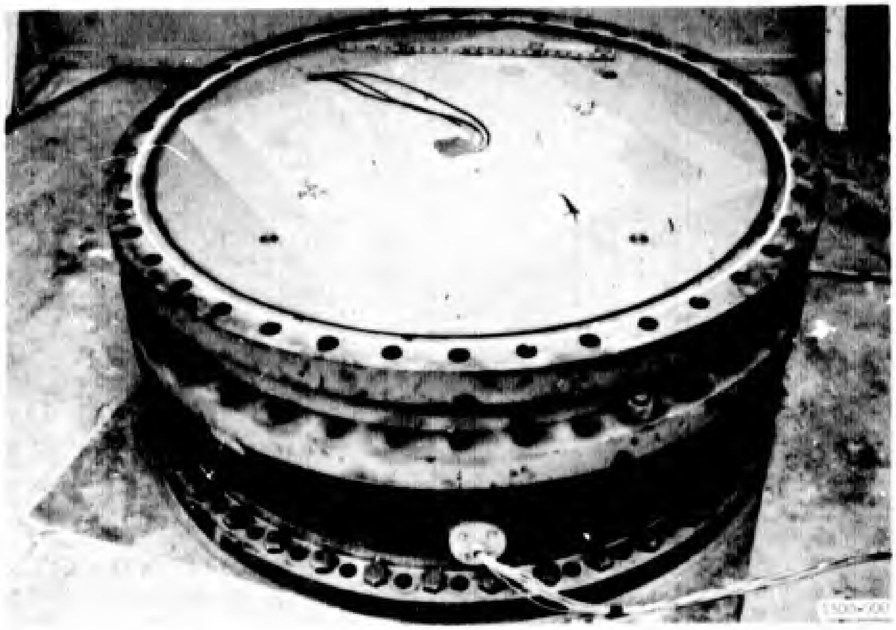
INSTRUMENTATION

During the laboratory static test program, longitudinal strain in the steel (when applicable) was measured for each slab at 12 locations including the strains at midspan. Concrete surface strains at the top face were measured at the center for each slab by means of a rosette-type gage. Deflection measurements were made at the slab midspan, at two locations at the inside edge of the support, and at two locations under the supported slab. Two pressure transducers mounted in the loading bonnet of the test device were used to measure the applied overpressure.

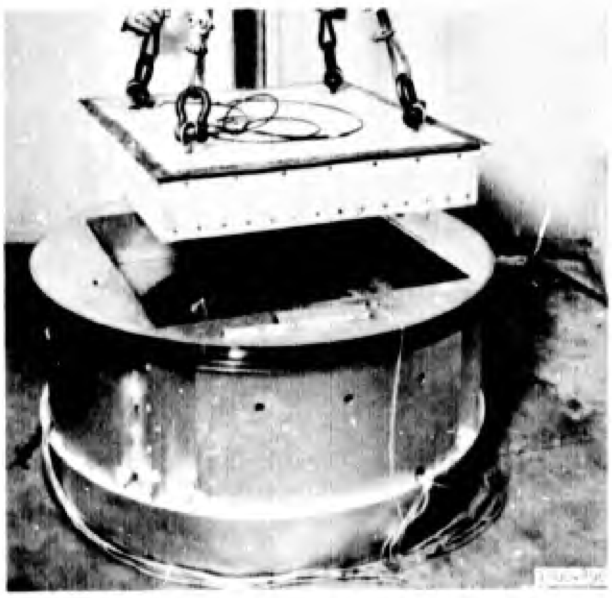
In the field test, 36 channels of instrumentation were recorded. The measurements for each slab included four steel strains (where applicable), midpoint deflection and acceleration, blast overpressure, and the pressure beneath the slab.

STATIC TEST FACILITY

The tests were conducted in the pressure chamber of the Small Blast Load Generator (SBLG) that has an inside diameter of 46.5 inches (Fig. 3a). The dimensions of the SBLG determined the size of the reaction structure that could be placed in it and, hence, the maximum length of slabs that could be accommodated. A steel reaction structure (Fig. 3b), with a 24-inch-diameter clear span and capable of sustaining static or dynamic overpressures of approximately 8,000 psi, was fabricated for use in all tests. This structure was designed to provide support extensions for changing support elevations to accommodate test slabs of various depths. During all



a. 1,000-psi pressure chamber



b. Steel reaction structure

Fig 3. Static test chamber and reaction structure

tests the tops of the slabs were sealed to prevent air or water pressure on the sides of the slabs.

The initial slab tests were conducted in the 1,000-psi static test device (Fig. 4a) of the SBLG. However, due to the requirement for higher overpressure to fail the slabs with high concrete strength as well as for deeper slabs, a 2,000-psi static test device was constructed (Fig. 4b) and is currently being used in the deep-slab test program.

FIELD TEST FACILITY

The field test experiment was conducted in conjunction with a project by the Air Force Weapons Laboratory (AFWL) and utilized the High Explosive Simulation Technique (HEST) for producing the overpressure. The overpressure environment was produced by the detonation of PETN in the form of detonating cord and was applied to a 40-foot-wide by 60-foot-long test bed situated in rock.

All specimens required a steel-shell structure to support the slabs during the test (Fig. 5a). Six support structures including the necessary hold-down rods and seal plates were constructed and placed in test pits which were excavated in the rock site. High strength concrete was cast around and beneath each support structure to complete the foundation (Fig. 5b).

RESULTS AND DISCUSSION

STATIC TESTS

Pertinent results obtained during the tests, i.e. maximum overpressure, maximum midpoint deflection, and mode of failure, are summarized in Table 1. The initial tests on the A specimens were conducted with air overpressure.

a. 1,000-psi device

b. 2,000-psi device

Fig. 4. Static test devices

a. Typical slab support structure

b. Support structures and slabs

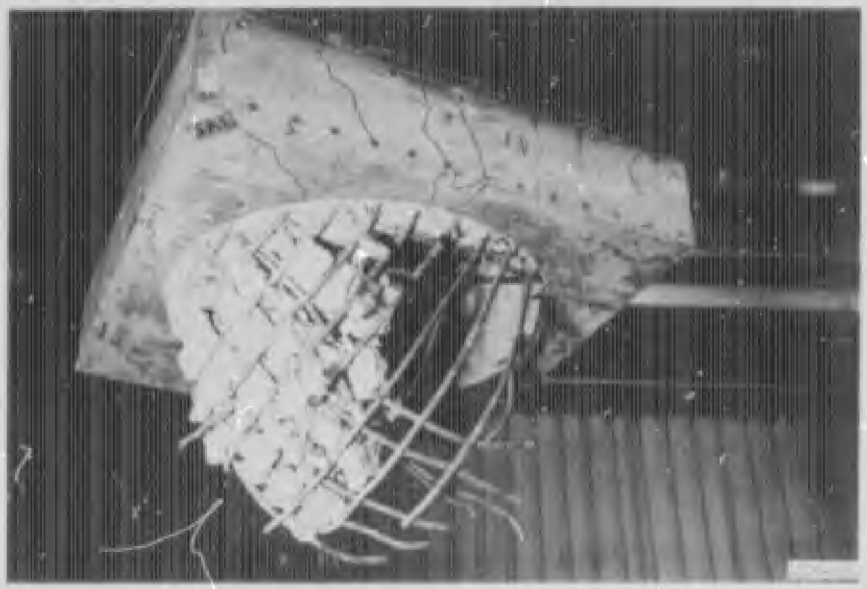
Fig. 5. Dynamic test support structures and slabs

Collapse of these slabs was instantaneous and very catastrophic (Fig. 6). The mode of failure was shear and a circumferential crack propagated from the edge of the support at approximately a 60-degree angle. This resulted in a sheared, cone-shaped element in the center portion of the slab. At collapse, the loading diaphragm ruptured, allowing the air overpressure to penetrate the slab and destroy the center concrete portion.

Tests on the B and C specimens were conducted with water as the loading medium. The same type of failure was observed when using water as when using air; however, as collapse was initiated the pressure decayed very rapidly and the center of the slab did not punch through. This water-loading technique was more efficient as the transducers located below the slab were not destroyed during testing. Specimen 5C1 was tested twice to pressure that was beyond the rated maximum overpressure capacity of the 1,000-psi testing device; however, failure of the slab did not occur and the remaining tests on these specimens were conducted in the 2,000-psi static test device.

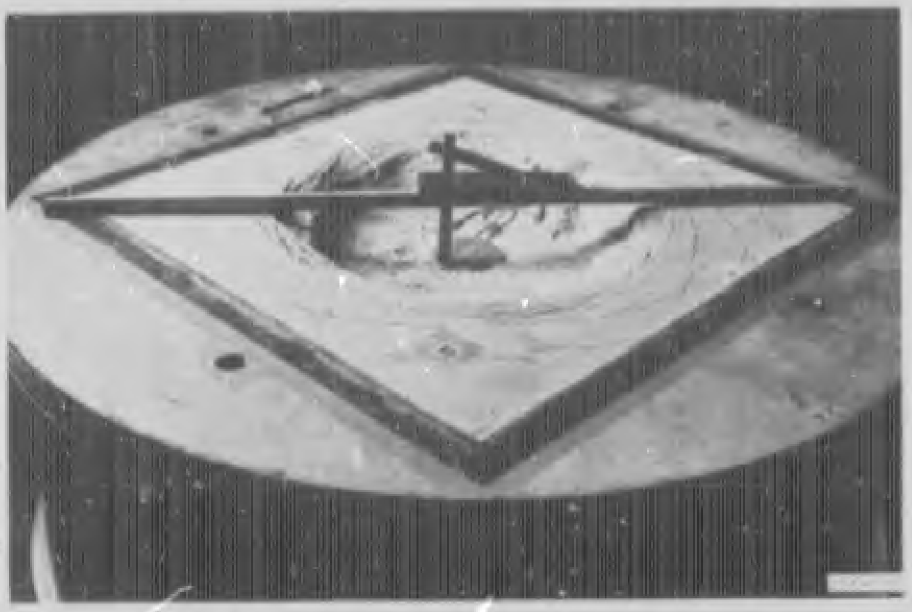
One slab each out of the D and E series was tested using air as the loading medium in order to validate that the failure response was the same with either method, i.e. air or water. The results of the tests indicated that the response was practically the same for either case (Figs. 7 and 8). Tests on the D specimens, which had an increase in tensile reinforcement from 0.99 to 1.49 percent, indicate that the increase in tensile steel does not appreciably change the resistance of the slab. The E, G, and I specimens were constructed of plain concrete, and except for an increase in the number of tension cracks at failure, the response of these slabs was similar to that of the slabs with reinforcement. In addition, the failure overpressures for the plain concrete slabs were approximately the same, although

a. Top view



b. Bottom view

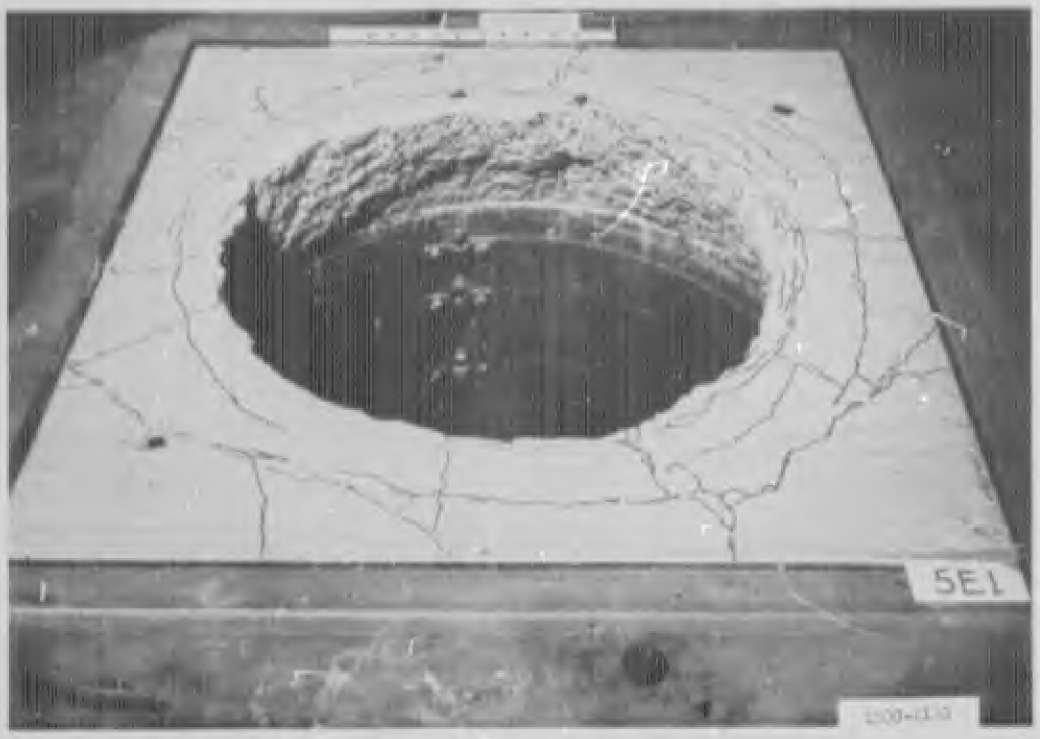
Fig. 6. Posttest view of deep slab 5A1 tested statically with air pressure (P_{so} = 953 psi)



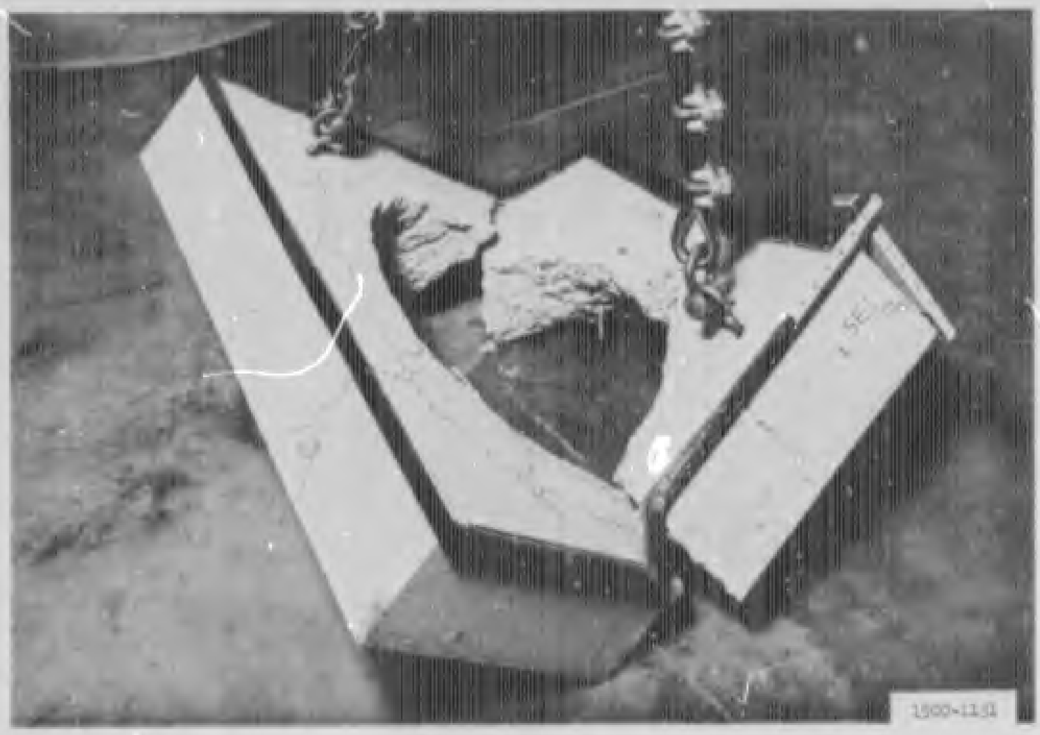
a. Top view

b. Bottom view

Fig. 7. Posttest view of deep slab 5D1 tested statically with water pressure (P_{so} = 1,047 psi)



a. Top view



b. Side view

Fig. 8. Posttest view of plain concrete deep slab 5E1 tested statically (P_{so} = 926 psi)

consistently less, as those for the reinforced concrete slabs with comparable concrete strengths (Fig. 14). This appears to have resulted from induced compression forces into the plane of the slabs caused by significant friction between the bottom of the slab and the support.

Ductility ratios for a number of the slabs tested are given in Table 3. As expected for deep slabs the ductility ratios are low; however, an increase in the tensile steel (D specimens) resulted in somewhat higher ductility ratios. The pressure with respect to midspan deflection is plotted in Fig. 9 for Slab 5B3 and is typical for the deep, reinforced concrete slabs tested.

The magnitude of failure overpressures ranged from 695 psi for the low strength plain concrete slabs (f'_c = 2,720 psi) to 1,432 psi for the slabs containing reinforcement and having a high concrete strength of 4,590 psi.

FIELD TEST

Peak value results obtained during the field test, i.e. overpressure and rise time, midpoint deflection and acceleration, and the mode of failure, are summarized in Table 2. General views of the slabs after removal of debris resulting from the shot are shown in Fig. 10. Posttest top views of each deep-slab specimen are shown in Fig. 11 and bottom views of the slabs containing reinforcement are shown in Fig. 12.

As shown in Figs. 10 to 12 all of the slabs failed and the mode of failure was shear. The failure patterns were similar to that for the slabs tested statically in the laboratory (Figs. 6 to 8). However, specimens E and F that were plain concrete slabs also had bearing failures on the short supported sides. It is believed that this crushing at the supports was caused by the overpressure being in excess of that anticipated (3,000 psi). Additionally, this excess in pressure is somewhat verified by the high accelerations

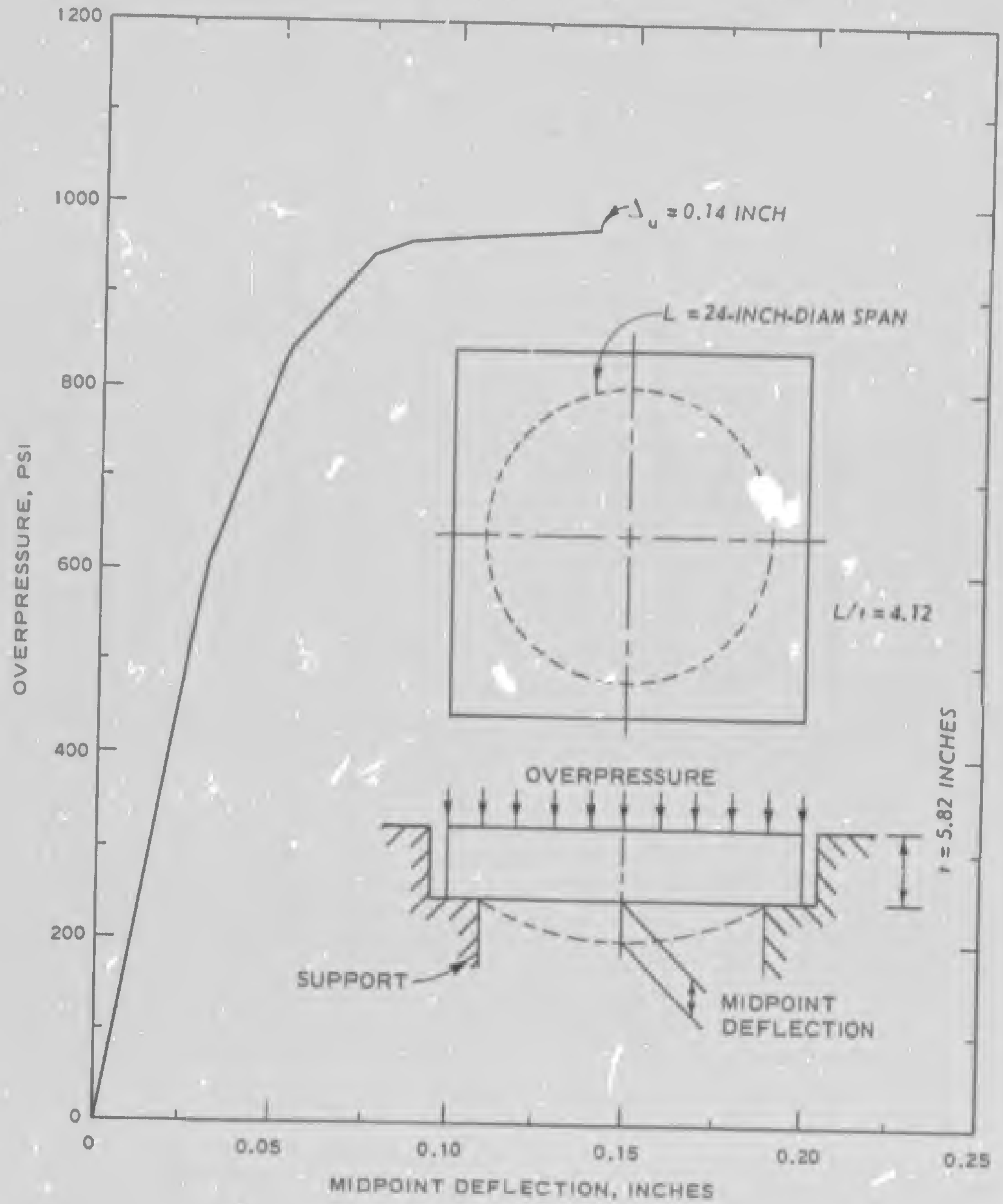


Fig. 9. Typical overpressure versus midpoint deflection curve for static tests, Slab 5B3

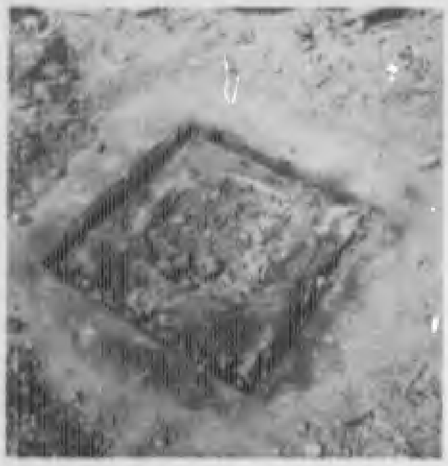
a. View from blast initiation end

b. Side view

Fig. 10. General view of deep slabs tested in field

Slab A

Slab B



Slab C

Slab D

Slab E

Slab F

Fig. 11. Posttest top view of deep slabs tested in field

Slab A

Slab B

Slab C

Slab D

Fig. 12. Posttest bottom view of deep slabs tested in field

measured (greater than 10,000 g's). The apparent peak pressure recorded was approximately 5,000 to 6,000 psi with a rise time of approximately 0.1 msec. At this time (0.1 msec), the blast pressure gage measurements became invalid due to the extreme amount of heat resulting from the shot and affecting the gage response. The predicted failure overpressures for the slabs are tabulated in Table 2 and were computed based on static information (see section on Response Analysis). Based on these predictions it would have taken approximately 4,880-psi pressure to fail the slabs having an L/t ratio of 2.6.

During the writing of this paper, no experimental data were available to use for describing the response to failure of deep slabs subjected to dynamic loading. However, dynamic nondestructive tests were conducted on slabs having L/t ratios of 5.5, 4.88, and 3.55 (References 2 and 3) and from these tests there was no evidence to indicate that the dynamic load capacities were lower than the static load capacities. If there is a change in the slab response, it is believed that it would be beneficial due to the possible increase in the concrete compressive strength under dynamic loading conditions; hence, from an attack point of view, this procedure would be proper for predicting target response. As reported in Reference 5, shear properties of concrete should increase under dynamic loading; however, the same problem exists now as it did then (1962), i.e. little data exist on this subject, especially for deep members.

RESPONSE ANALYSIS

Summarized here are the only applicable and available solutions based on experimental data for defining the static failure overpressure of deep slabs. Shear stress in the slab was used as the basic criteria in the solutions, since available experimental results have shown that the governing

mode of failure of deep slabs is shear (References 1 to 4).

An empirical solution for predicting the ultimate shear stress and, hence, the failure overpressure of deep slabs supported flat over a circular opening has been formulated by the University of Illinois (References 2 and 4). The solution is based on experimental data from tests on deep, circular slabs having an L/t ratio of 3.5. It was found that for circular slabs the ultimate shear stress, v_u , is a function of $\sqrt{f'_c}$ and is represented by the following expression:

$$v_u = k\sqrt{f'_c} \text{ , psi} \tag{1}$$

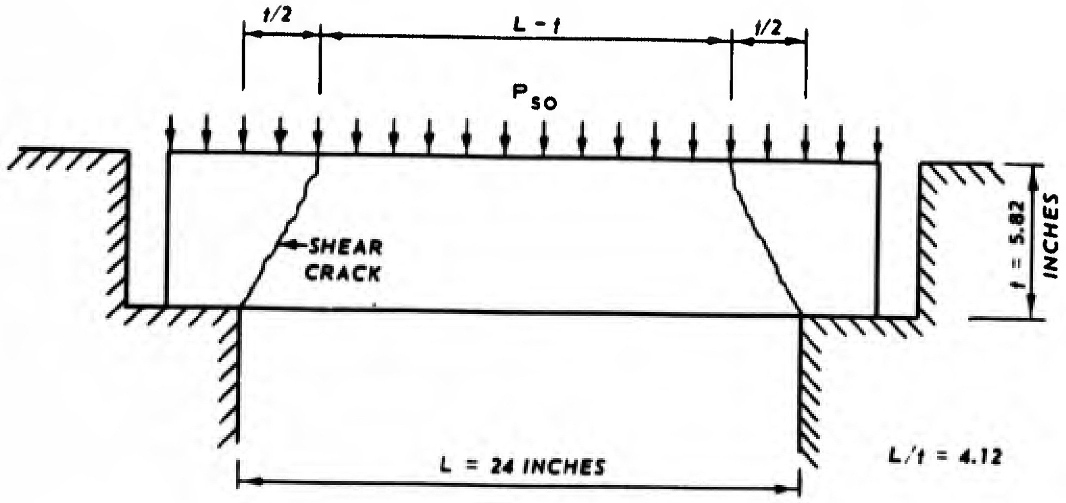
where

k = an empirical constant

f'_c = compressive strength of concrete

and occurs on a section equal to the full slab thickness, t , and located a distance t from the face of the support. It was determined that the empirical constant k had values ranging from 9.0 to 13.5 and an average value of 11.2. The failure overpressure, P_{so} , was found to be equal to v_u multiplied by the ratio of the shear area, A_{SH} , and the loaded shear area, A_L .

The results of the static tests reported herein on deep, square slabs having an L/t ratio of 4.12 have been used to modify the solution and make it applicable for slabs having this geometry (Fig. 13). Based on these results, two modifications were made to the solution as follows: (1) the ultimate shear stress is located a distance, t/2 , from the face of the support; and (2) the empirical constant, k , for determining the ultimate shear stress was found to have maximum, average, and minimum values of 16.4, 13.1,



$$P_{so} = v_u (A_{sh}/A_L)$$

WHERE:

v_u = ULTIMATE SHEAR STRESS = $k\sqrt{f'_c}$

A_{sh} = SHEAR AREA = $\pi t (L - t)$

A_L = LOADED SHEAR AREA = $\frac{\pi}{4}(L - t)^2$

k = EMPIRICAL CONSTANT HAVING RANGE OF VALUES OF 16.4, 13.1, AND 10.3

Fig. 13. Empirical solution for predicting failure of deep, square slabs

and 10.3, respectively. These changes resulted in the following empirical solution for predicting the static failure overpressure, P_{so} , of deep, square slabs:

$$P_{so} = v_u \left(\frac{A_{SH}}{A_L} \right) \tag{2}$$

where

A_{SH} = shear area = $\pi t(L - t)$

A_L = loaded shear area = $\frac{\pi}{4} (L - t)^2$

The relation between deep-slab static failure overpressure and the concrete compressive strength is shown in Fig. 14. One of the significant results that has been determined from this investigation, and is presented in the figure, is that the failure overpressure appears to be primarily dependent on the strength of the concrete in the slab. The predicted failure overpressures using the modified solution (Eq. 2) are plotted in Fig. 14 and appear to form a reasonable bound for the data. This solution is sufficient for deep, square slabs having an L/t ratio of 4.12, and it is anticipated that when experimental data are available for deeper slabs the solution can be modified to predict deep-slab failure overpressures for the full range of span-to-thickness ratios (from 4.12 to 1.89) of interest.

CONCLUSIONS

STATIC TESTS

The conclusions drawn herein are based on experimental tests of deep, reinforced and plain concrete slabs having a span-to-thickness ratio of 4.12 and a square geometry, and supported flat over a circular span.

Mode of Failure. The governing mode of failure for square, deep,

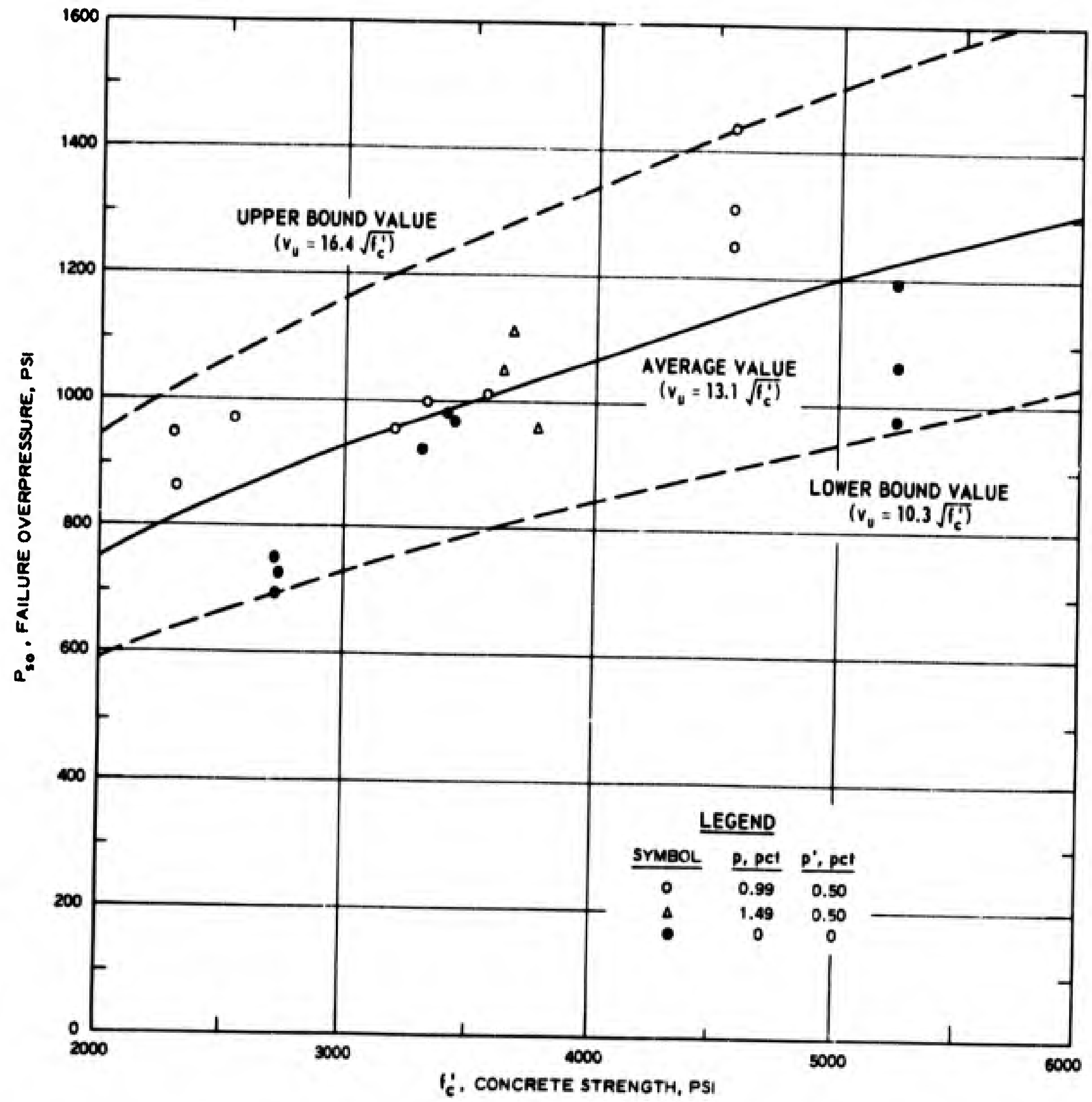


Fig. 14. Relation between deep-slab static failure overpressure and concrete strength

reinforced and plain concrete slabs was shear. Collapse of the slabs was instantaneous and very catastrophic. At collapse, a circumferential crack had propagated from the edge of the support at approximately a 60-degree angle and resulted in a sheared, cone-shaped element in the center portion of the slab.

Concrete Strength. From the tests conducted in the deep-slab study, one of the significant results obtained is that failure of the slabs is primarily dependent on the concrete compressive strength. When determining the target vulnerability of such structures, this effect is significant since the amount of reinforcing steel does not have to be taken into account in predicting the failure overpressure.

Reinforcement. The tests have shown that increase in two-way tensile reinforcement from 0.99 to 1.49 percent does not appreciably change the resistance of the slab.

Plain Concrete Slabs. The failure overpressures for the plain concrete slabs having compressive strengths in the range of 2,500 to 5,000 psi were somewhat less, although not significantly, than those for the reinforced concrete slabs with comparable concrete strengths. This considerable resistance of the plain concrete slabs appears to have been produced by significant friction between the bottom of the slab and the support and resulted in induced compression forces into the plane of the slabs.

Ductility Ratio. The results indicated that the reinforced concrete slabs had low ductility ratios of approximately 2 to 3. The plain concrete slabs appeared to have no ductility and collapsed completely.

Response Analysis. The results from these tests on deep, square slabs have been used to modify an existing empirical solution based on shear

stress criteria for circular slabs and make it applicable for slabs having this geometry.

FIELD TESTS

Six deep, reinforced and plain concrete slabs having span-to-thickness ratios of 3.5 and 2.6 were subjected to an apparent airblast-induced overpressure of approximately 5,000 to 6,000 psi. The measured overpressure was greater than anticipated and as a result failure of all slabs occurred. The mode of failure was shear, and from posttest visual examination of the slabs their response appeared to be similar to the shallower deep slabs tested statically. Although the overpressure was greater than that required to fail the slabs, there was no evidence to indicate that the dynamic load capacities were lower than the static load capacities.

TABLE 1 DEEP-SLAB PROGRAM, SUMMARY OF STATIC TEST RESULTS

Slab No.	Two-Way Reinforcement		Concrete Strength f'_c	Loading Method (Static)	Test Results		
	Tensile	Compressive			Maximum Overpressure	Maximum Midpoint Deflection	Mode of Failure
	pct	pct	psi		psi	inches	
Phase 1 - L/d of 4.67, L/t of 4.12:							
Task A Tests - Concrete Strength:							
5A1	0.99	0.50	3,210	Air	953	0.16	Shear
5A2	0.99	0.50	3,330	Air	1,000	0.12	Shear
5A3	0.99	0.50	3,580	Air	1,008	0.13	Shear
5B1-1	0.99	0.50	2,320	Water	862	--	No failure
5B1-2	(Second test on 5B1)			Water	866	0.23	Shear
5B2	0.99	0.50	2,310	Water	948	0.14	Shear
5B3	0.99	0.50	2,550	Water	970	0.14	Shear
5C1-1	0.99	0.50	4,590	Water	1,076	--	No failure
5C1-2	(Second test on 5C1)		4,590	Water	1,122	--	No failure
5C1-3	(Third test on 5C1)		4,590	Water	1,432	0.45	Shear
5C2	0.99	0.50	4,590	Water	1,247	--	Shear
5C3	0.99	0.50	4,590	Water	1,306	--	Shear
Task B Tests - Reinforcement:							
5D1	1.49	0.50	3,640	Water	1,047	0.32	Shear
5D2	1.49	0.50	3,780	Water	958	0.27	Shear
5D3	1.49	0.50	3,680	Air	1,108	--	Shear
5E1	0	0	3,320	Water	926	--	Shear
5E2	0	0	3,420	Water	980	--	Shear
5E3	0	0	3,440	Air	970	--	Shear
Task C Tests - Verification (Plain Concrete Slabs):							
5G1	0	0	2,720	Water	695	0.13	Shear
5G2	0	0	2,750	Water	728	0.11	Shear
5G3	0	0	2,720	Water	752	0.11	Shear
5I1	0	0	5,250	Water	1,195	--	Shear
5I2	0	0	5,250	Water	976	--	Shear
5I3	0	0	5,250	Water	1,062	--	Shear

TABLE 2 DEEP-SLAB PROGRAM, SUMMARY OF FIELD TEST RESULTS

Duration of pressure pulse was not obtained.

Slab No.	Two-Way Reinforcement		Concrete Strength f'_c	Overpressure			Accelera-tion Downward	Deflec-tion	Mode of Failure
	Tensile	Compres-sive		Predicted Static Failure	Blast Pressure	Rise Time			
	pct	pct	psi	psi	psi	msec	g's	inches	
L/t of 3.5; L/d of 3.88:									
A	1.00	0.47	5,550	2,680	Peak pressure recorded approximately 5,000 to 6,000 psi	Rise time to peak pressure approximately 0.1 msec	21,100	0.25	Shear
C	1.00	0.47	5,550	2,680			14,000	0.17	Shear
E	0	0	4,750	2,480			--	0.15	Shear with short supported sides crushing in bearing
L/t of 2.6; L/d of 2.8:									
B	1.02	0.51	3,150	4,880	Peak pressure recorded approximately 5,000 to 6,000 psi	Rise time to peak pressure approximately 0.1 msec	9,760	0.25	Shear
D	1.02	0.51	3,150	4,880			10,300	0.44	Shear
F	0	0	3,150	4,880			11,150	0.28	Shear with short supported sides crushing in bearing

TABLE 3 STATIC RESULTS, DUCTILITY RATIOS

Slab No.	Yield Deflection Δ_y	Ultimate Deflection Δ_u	Ductility Ratio $\mu = \Delta_u/\Delta_y$
	inches	inches	
5A2	0.07	0.12	1.72
5A3	0.04	0.13	3.25
5B1-2	0.11	0.23	2.09
5B3	0.05	0.14	2.80
5D1	0.10	0.32	3.20
5D2	0.07	0.27	3.86
5C1-3	0.16	0.45	2.81

APPENDIX I.--REFERENCES

---

1. Beadle, C. W., Dally, J. W., and Riley, W. F., "Rigidity and Strength of Composite Plates," Journal, Engineering Mechanics Division, American Society of Civil Engineers, Vol. 90, Dec., 1964, pp. 211-241.

2. Gamble, W. L., et al., "A Study of Launch Facility Closures," SAMSO-TR-67-15, Department of Civil Engineering, University of Illinois, Urbana, Ill., Nov., 1967.

3. Gregory, R. K., et al., "Response of Deep Reinforced Concrete Slabs," TDR No. WL-TDR-64-54, Southwest Research Institute, San Antonio, Tex., Feb., 1965.

4. Iten, R. M., and Gamble, W. L., "Behavior of Missile Silo Closures Designed to Resist High Overpressures," SAMSO-TR-67-72, Department of Civil Engineering, University of Illinois, Urbana, Ill., Mar., 1968.

5. Newmark, N. M., and Haltiwanger, J. D., "Air Force Design Manual; Principles and Practices for Design of Hardened Structures," Technical Documentary Report No. AFSWC-TDR 62-138, Air Force Special Weapons Center, Kirtland Air Force Base, N. Mex., Dec., 1962.

APPENDIX II.--NOTATION

The following symbols are used in this paper:

A_L = loaded shear area on surface of slab, $inches^2$

A_{SH} = shear area, $inches^2$

d = effective depth, distance from top compressive fiber to centroid of tensile reinforcement, inches

f'_c = compressive strength of concrete, psi

k = empirical constant for determining the ultimate shear stress in deep slabs

L = clear span length of slabs, inches

p = ratio of area of tensile reinforcement to effective area of concrete, percent

p' = ratio of area of compressive reinforcement to effective area of concrete, percent

P_{so} = static overpressure to produce failure of slab, psi

t = total thickness of slab, inches

v_u = ultimate shear stress in deep slabs, psi

Δ_u = ultimate midpoint deflection, inches

Δ_y = deflection at yield, inches

μ = ductility ratio, Δ_u/Δ_y

π = a constant (3.14)

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Miss.	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

RESPONSE OF DEEP REINFORCED AND UNREINFORCED CONCRETE SLABS TO STATIC AND DYNAMIC LOADING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (First name, middle initial, last name)

Gayle E. Albritton

6. REPORT DATE October 1968	7a. TOTAL NO. OF PAGES 34	7b. NO. OF REFS 5

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper N-68-5
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Defense Atomic Support Agency Washington, D. C.

13. ABSTRACT The objectives of this investigation were to study experimentally the response of deep, two-way reinforced and plain concrete slabs subjected to static overpressures and to determine the response to failure of deep slabs subjected to airblast overpressure. In the static program, tests were conducted on twenty-one deep-slab specimens having a constant span-to-thickness ratio of 4.12. The parameters varied during the tests were the steel percentage and concrete strength; also the study included tests on plain concrete slabs. Six additional deep slabs were included in a field test, with three slabs having a span-to-thickness ratio of 3.5 and three a ratio of 2.6. All of the slabs had a model scale ratio of 1/7 of the assumed prototype deep slab, had a constant square length of 30.25 inches, and were supported flat over a 24-inch-diameter clear span. The magnitude of static failure overpressures ranged from 695 psi for the low strength plain concrete slabs to 1,432 psi for the slabs containing reinforcement and having a high concrete strength of 4,590 psi. The slabs tested in the field were subjected to an apparent airblast overpressure of approximately 5,000 to 6,000 psi. Collapse of the slabs was instantaneous and very catastrophic, and the mode of failure for all slabs was shear. The results from the static tests indicated that the slabs had low ductility ratios of approximately 2 to 3. The tests have shown that increase in tensile reinforcement from 0.99 to 1.49 percent does not appreciably change the resistance of the slab. The failure overpressures for plain concrete deep slabs were less, although not significantly, than those for reinforced concrete slabs with comparable concrete strengths. In the field test, the airblast overpressure was greater than that required to fail the slabs; however, there was no evidence to indicate that the dynamic load capacities were lower than the static load capacities.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Airblast						
Concrete slabs						
Concrete, reinforced						

Unclassified

Security Classification